Update on sPHENIX

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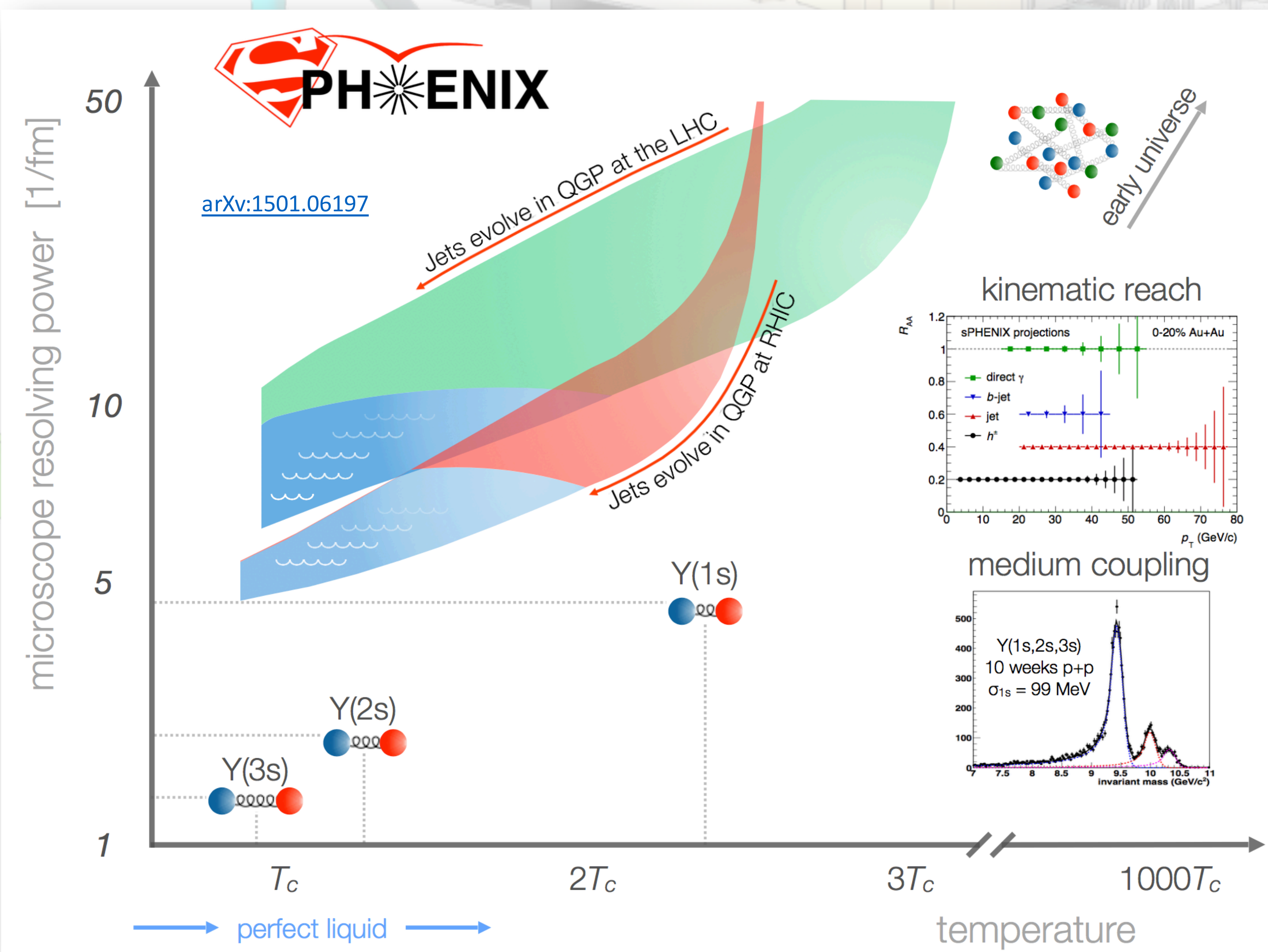
for sPHENIX Collaboration

Santa Fe Jets and Heavy Flavor Workshop

February 14, 2017



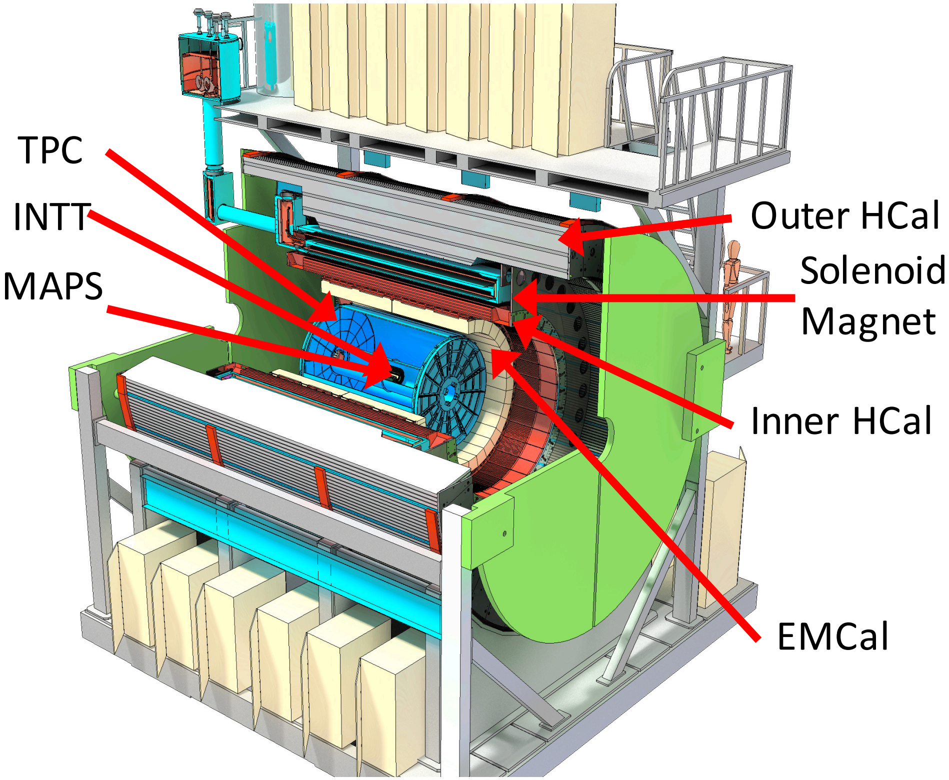
sPHENIX
arXv:1501.06197
microscope resolving power [1/fm]
50
10
5
1
Jets evolve in QGP at the LHC
Jets evolve in QGP at RHIC
early universe
kinematic reach
sPHENIX projections
0-20% Au+Au
direct γ
b-jet
jet
h±
R_{AA}
p_T (GeV/c)
medium coupling
Υ(1s,2s,3s)
10 weeks p+p
σ1s = 99 MeV
invariant mass (GeV/c²)
Υ(1s)
Υ(2s)
Υ(3s)
Tc
2Tc
3Tc
1000Tc
perfect liquid
temperature

Proposed sPHENIX detector

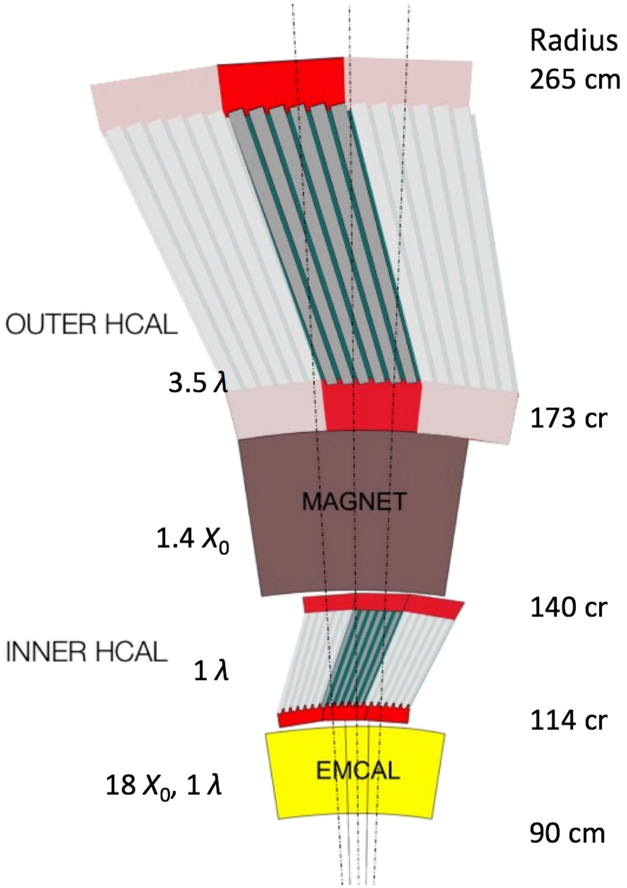
- ❖ Hermetic EMCal + HCal
  - ❖ Jet relatively directly comparable with LHC

- ❖ Precise and fast tracking
  - ❖ Time Projection Chamber (TPC)
  - ❖ Silicon strip intermediate tracker (INTT)
  - ❖ Monolithic Active Pixel Sensor (MAPS)

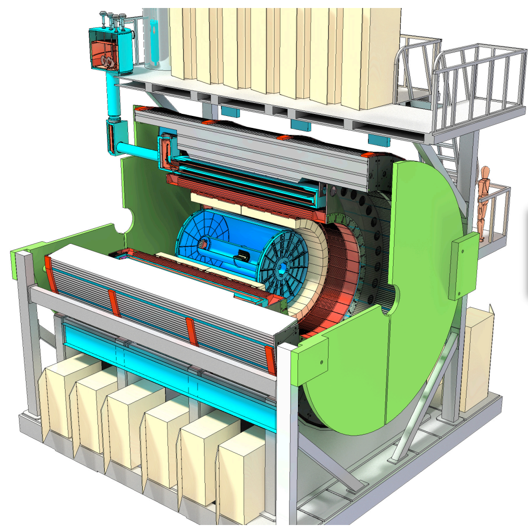
- ❖ High speed DAQ: 15kHz
  - ❖ 100 billion MB Au+Au in 22 weeks

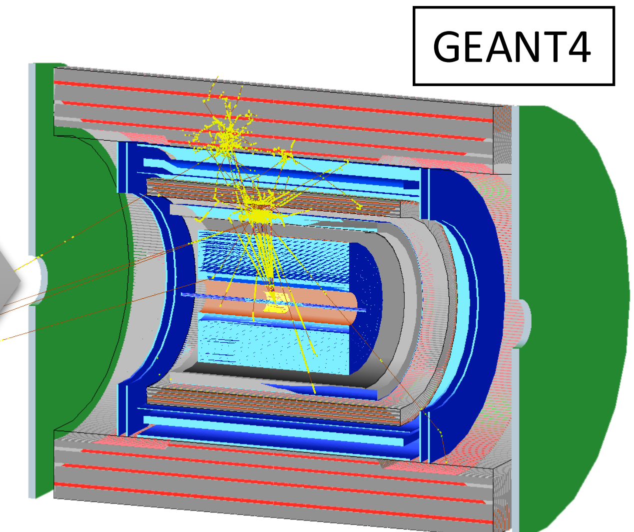


Calorimetry: Design and Simulation



Physics Goal	Detector Requirement
Jets/Fragmentation Functions/jet substructure	Single particle Resolution: σ/E < 100%/√E
Distinguish Upsilon States	Good e/π separation
HF jet tagging	Electron ID





Beam

Beam Test in FNL

Calorimetry: Beam Test, EMCal

Beam Test in FNL

- Good consistency with simulation
- Performance satisfies requirement
- Paper coming soon

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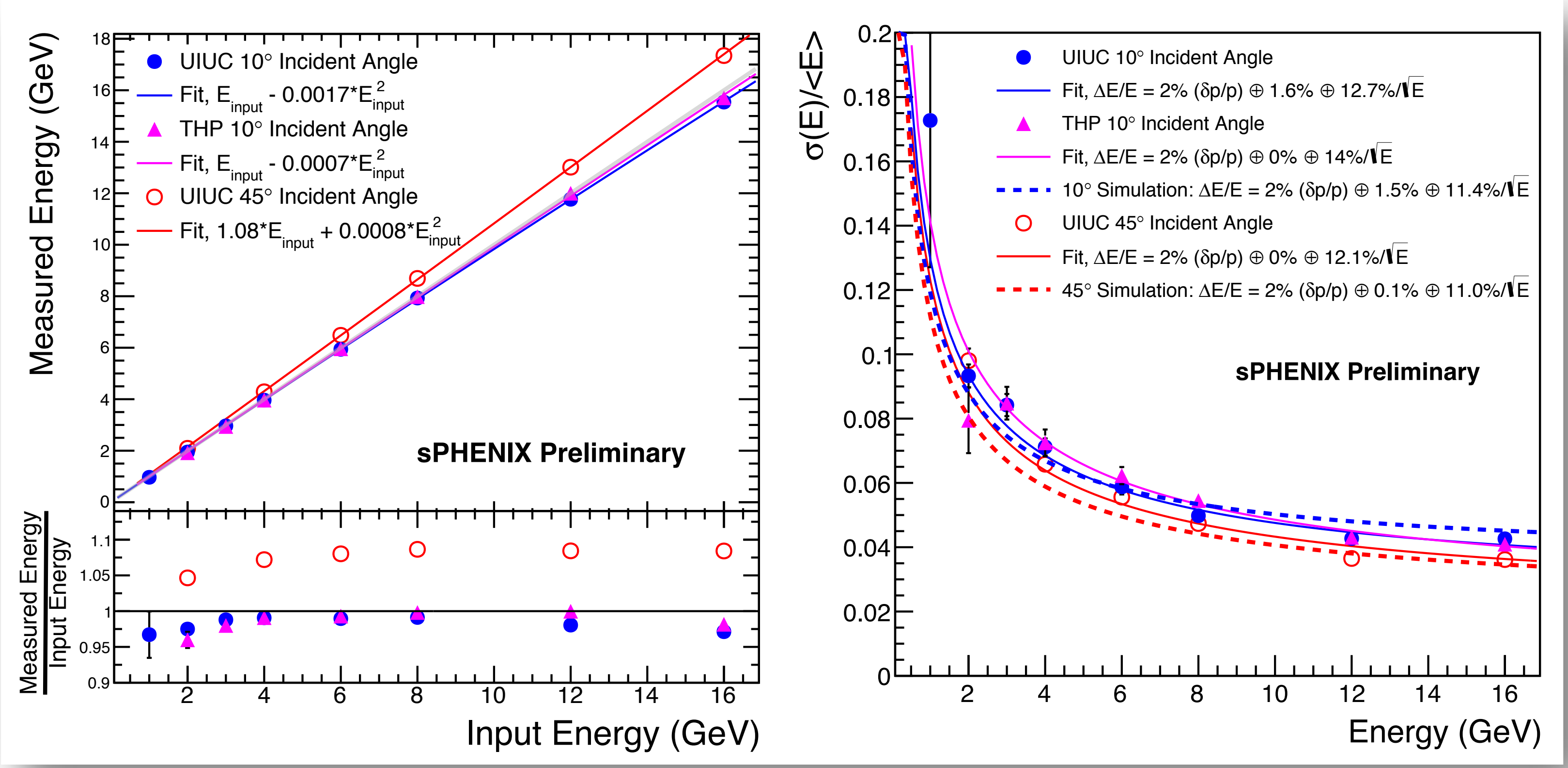
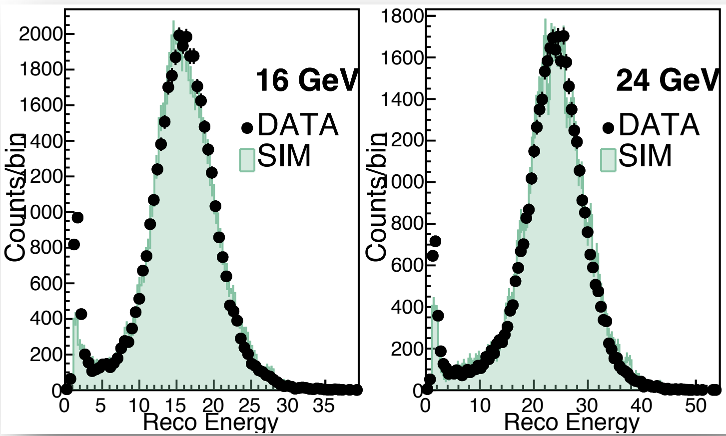


Calorimetry: Beam Test, HCal



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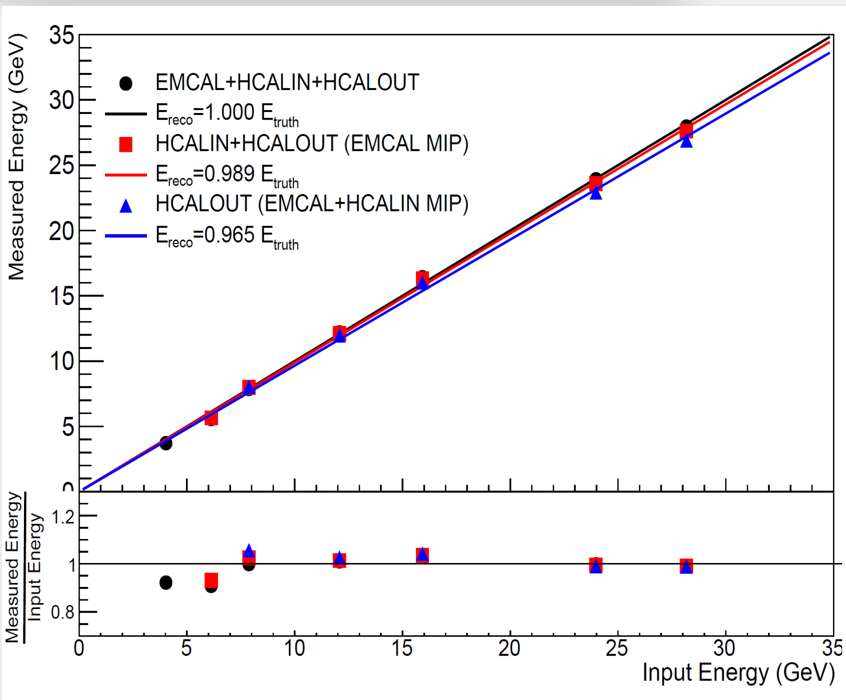
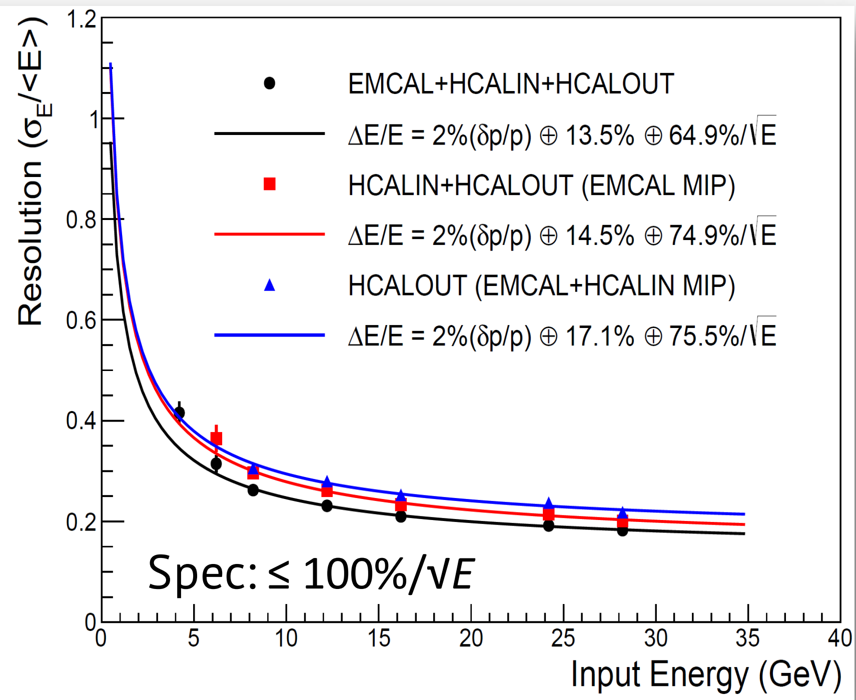
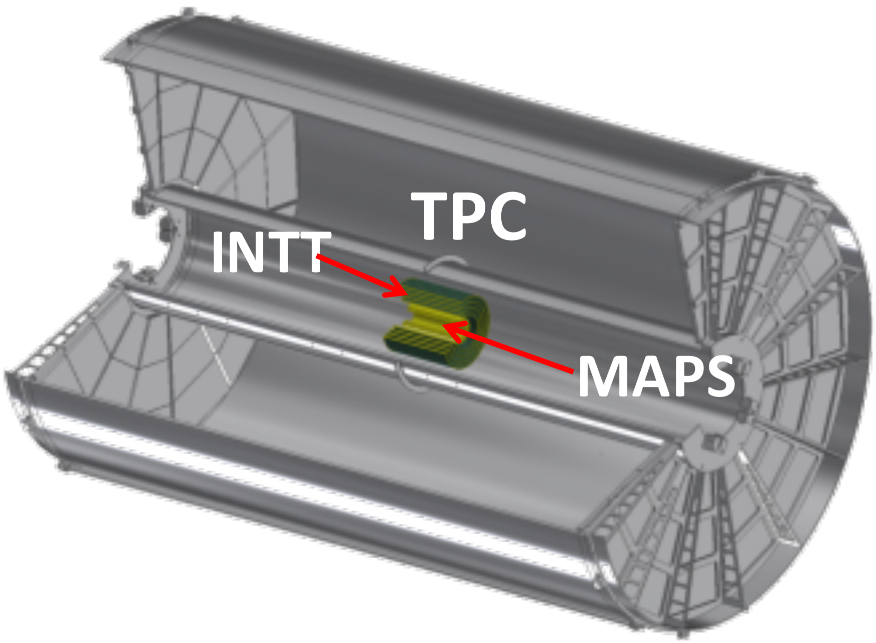


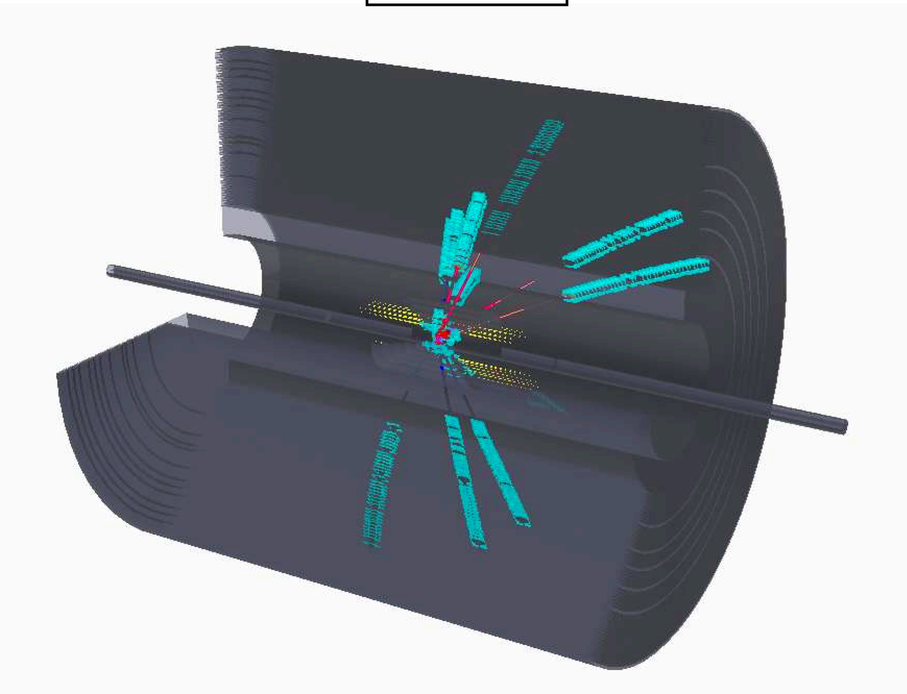


Tracking

Physics Goal	Detector Requirement
Fragmentation Functions	Excellent Momentum Resolution: dp/p ~ 0.2%p to > 40 GeV/c
Jet Substructure	Excellent track pattern recognition
Distinguish Upsilon States	Mass resolution: $\sigma_M < 100$ MeV/c^2
HF jet tagging	Precise DCA resolution $\sigma_{DCA} < 100$ μm



GEANT4



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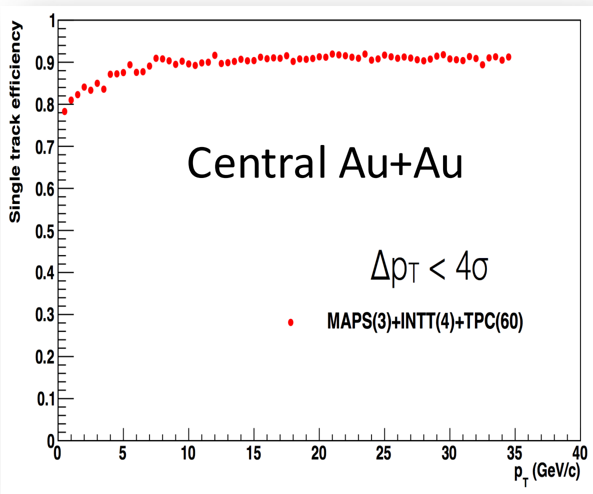
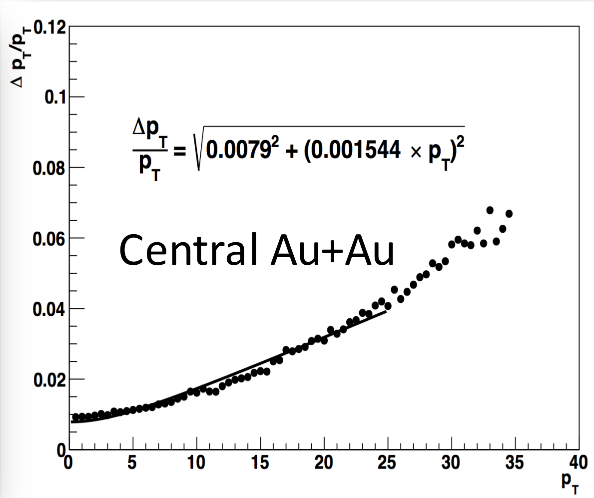
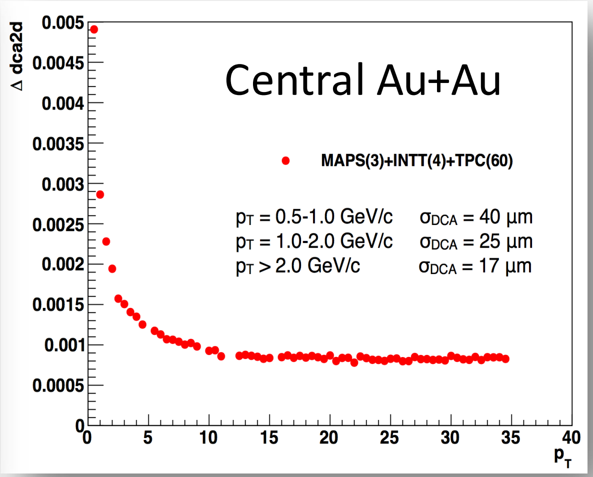


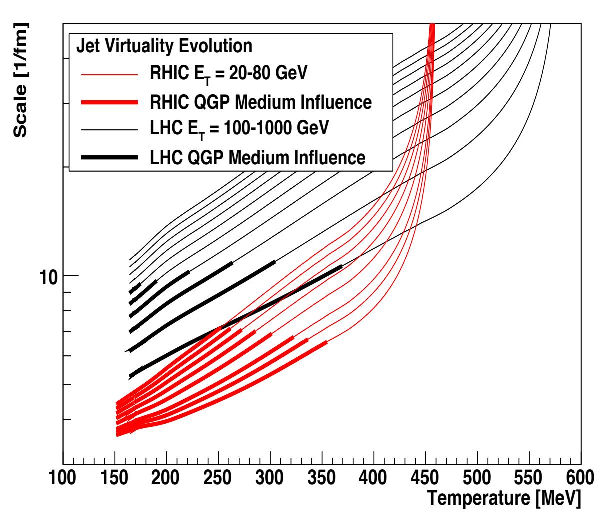


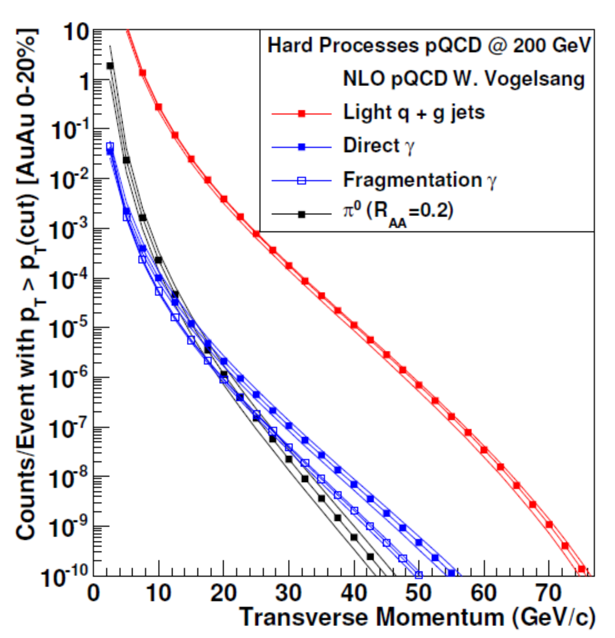


*Simulation results in Sep. 2016

Jet at sPHENIX

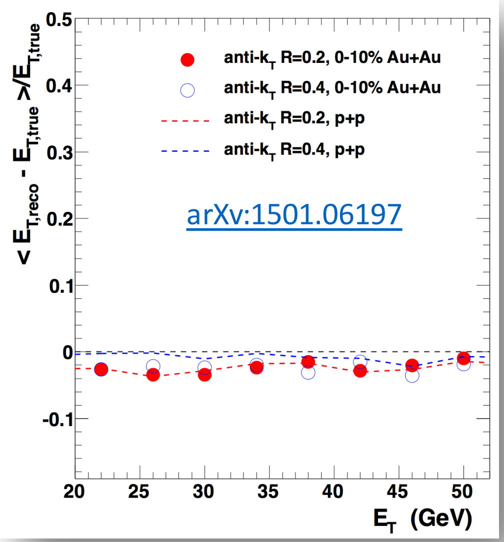
- Jets interact minimally until their virtuality ~ medium virtuality
  - Jets from the highest collision energies are mostly vacuum (pQCD) dominated
  - **Measure low E_T jets at RHIC energies!**
- Sample ~100 billion Au+Au events in 1 year
  - 10^7 jets > 20 GeV
  - 10^6 jets > 30 GeV
  - 80% are dijet events
  - 10^4 direct γ > 20 GeV
- Required Detector Performance
  - Single particle resolution: $\sigma_E/E < 100\%/\sqrt{E}$
  - Jet: $\sigma_E/E < 120(150)\%/\sqrt{E}$ in p+p(Au+Au)
  - Photon Energy resolution $\sigma_E/E<15\%/\sqrt{E}$
  - dp/p ~ 0.2% p to > 40 GeV/

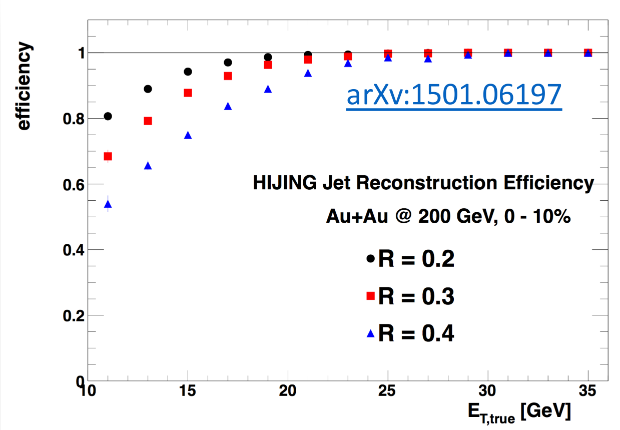


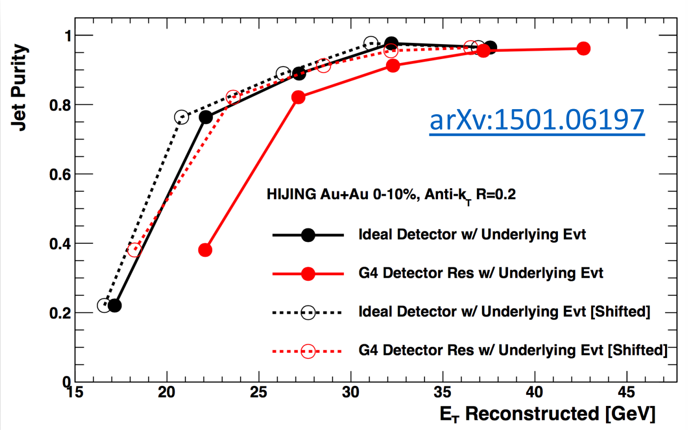


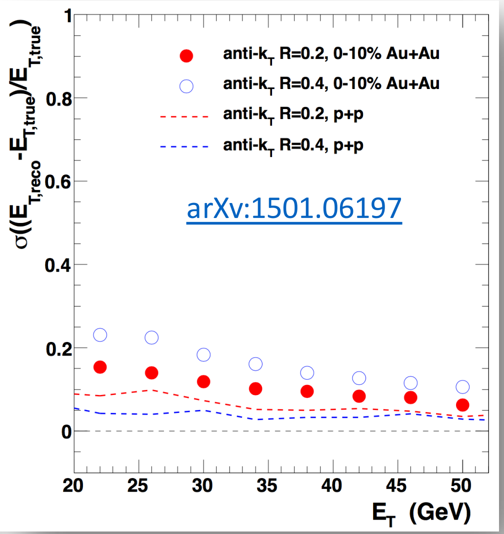
sPHENIX Jet Reconstruction Performance

- Anti-k_T method, FastJet Package
- Full GEANT4 simulation for p+p for detector response
- Fast simulation for Au+Au for UE effect
    - Background subtracted
    - Method based on ATLAS method, arXiv:1203.1353
- Full GEANT4 simulation for Au+Au combined with knowledge from beam test will be used to evaluate the performance of the background subtraction
    - jet energy measurements
    - photon isolation
    - calorimeter clustering



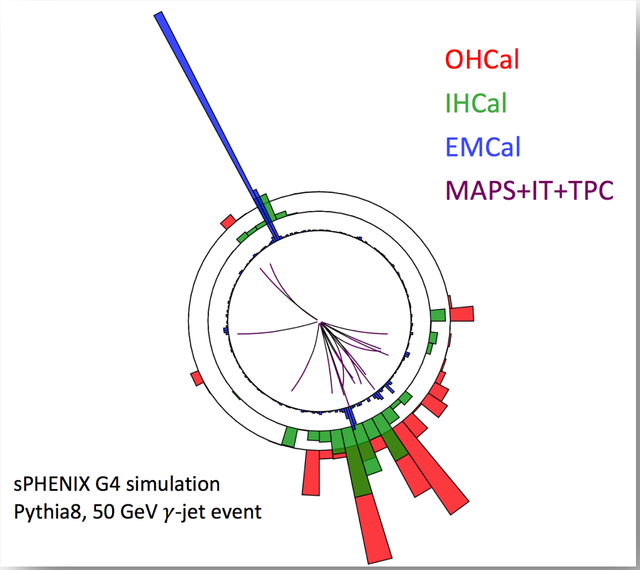




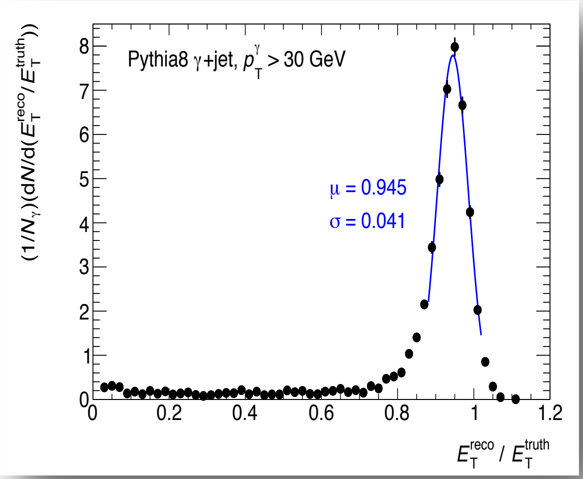


γ jet

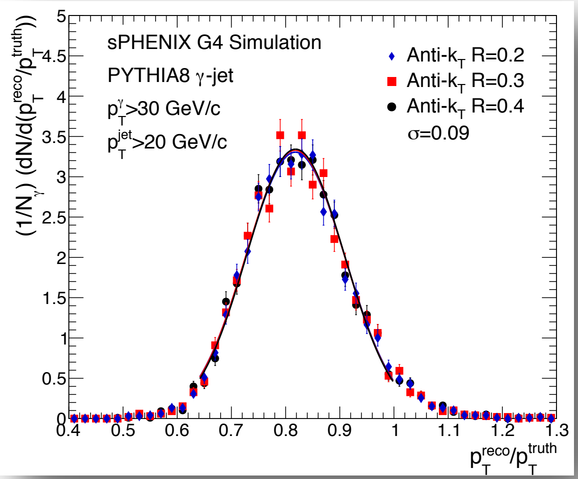
- γ jet events are the “golden channel" for the calibration of initial quark energy
- Simulation of γ-jet events with PYTHIA
  - Compare energy clustered into jet versus photon
  - Effect of detector resolution
- Performance with heavy ion background will be quantified in the future



Photon Response



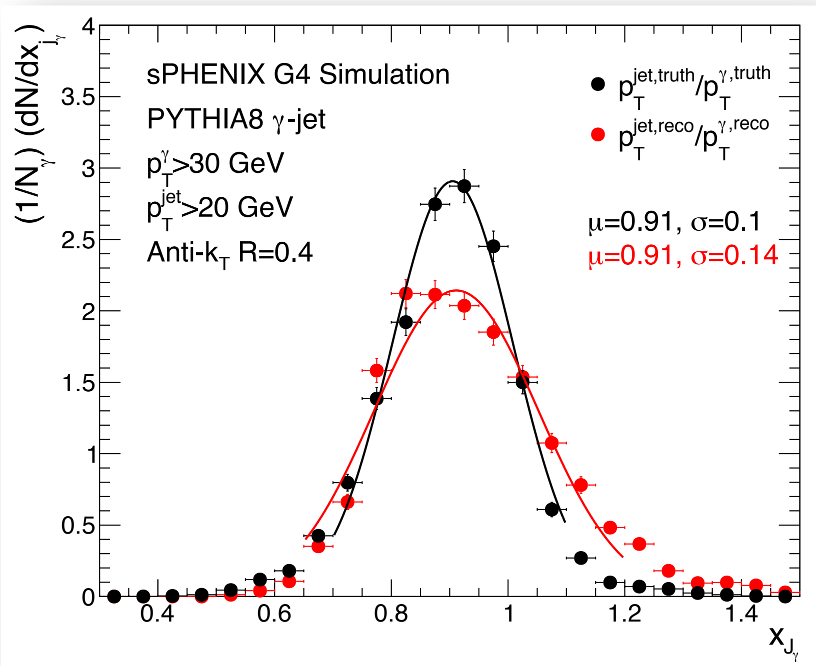
Jet Response

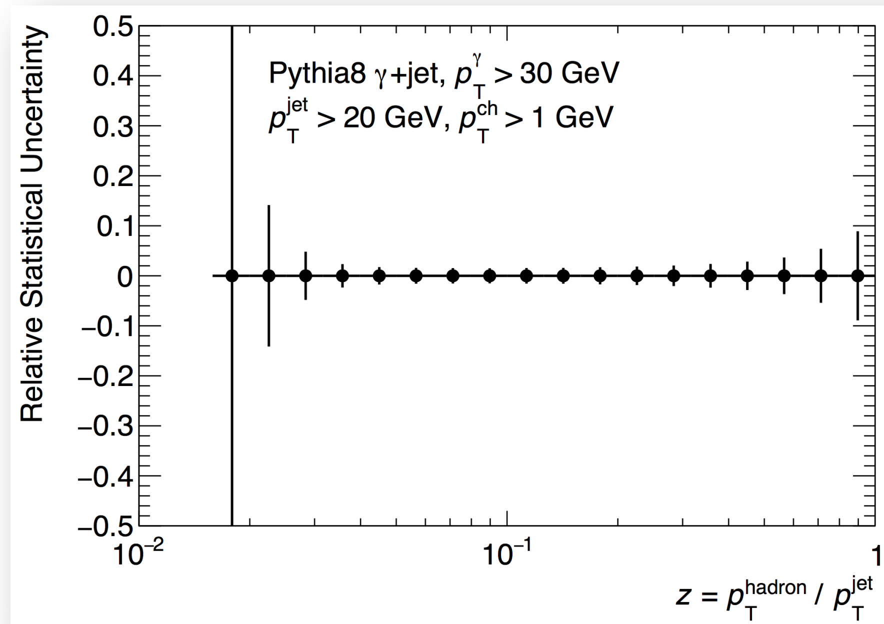


γ jet

$$X_{J\gamma} = \frac{p_T^{\gamma}}{p_T^{jet}}$$

γ tagged Jet FF, expected relative statistical uncertainty with 10k γ jet events.

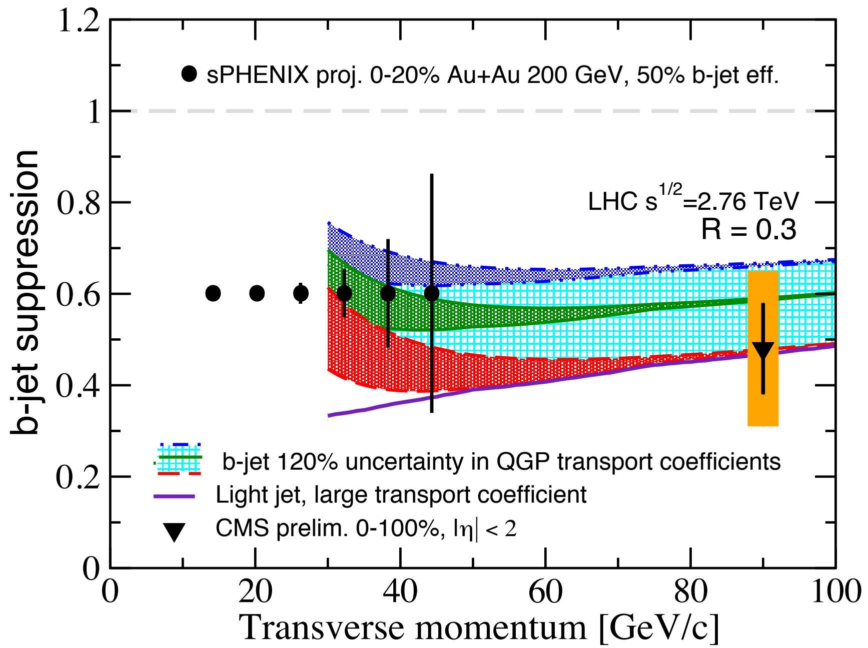


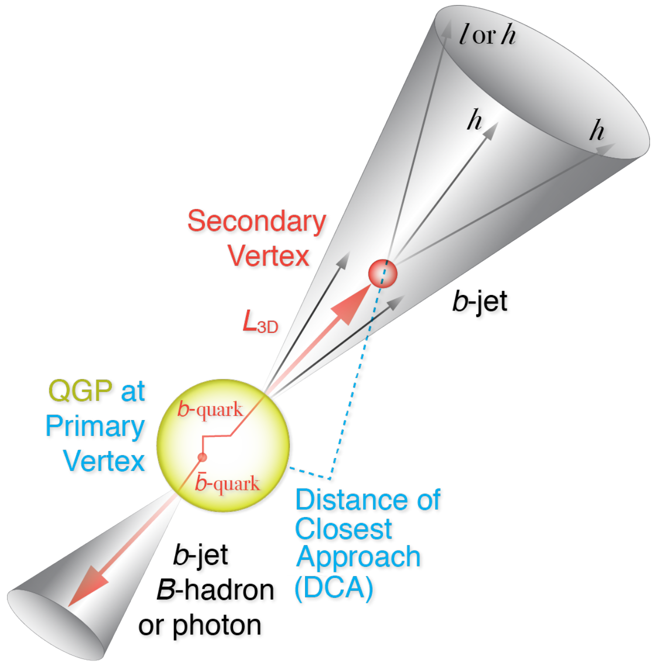


b-jet

- b-jet: unique energy loss signatures due to large mass ($4.2 GeV/c^2$)
- b-jet at RHIC:
  - Reconstruct jet at energy as low as 15 GeV, where the quark mass is more important for the energy loss mechanisms
  - Main process is g+g⟶b+b or g+b⟶g+b.

- b-jet tagging at sPHENIX:
  - Very good DCA resolution (25 μm for p_T 1-2 GeV/c) compared with B, D meson life time.
  - Acceptable DCA tail with preliminary HIJING embedding simulation.
  - Various tagging methods.





b-jet tagging: Full GEANT4 Simulation for p+p and Au+Au

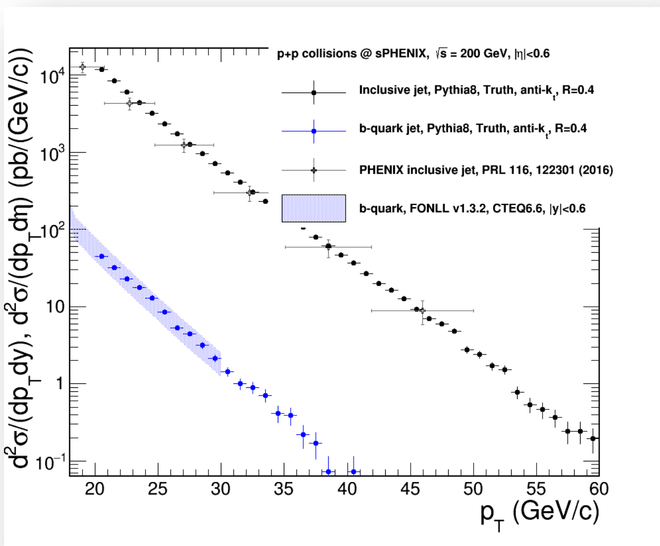
Input:

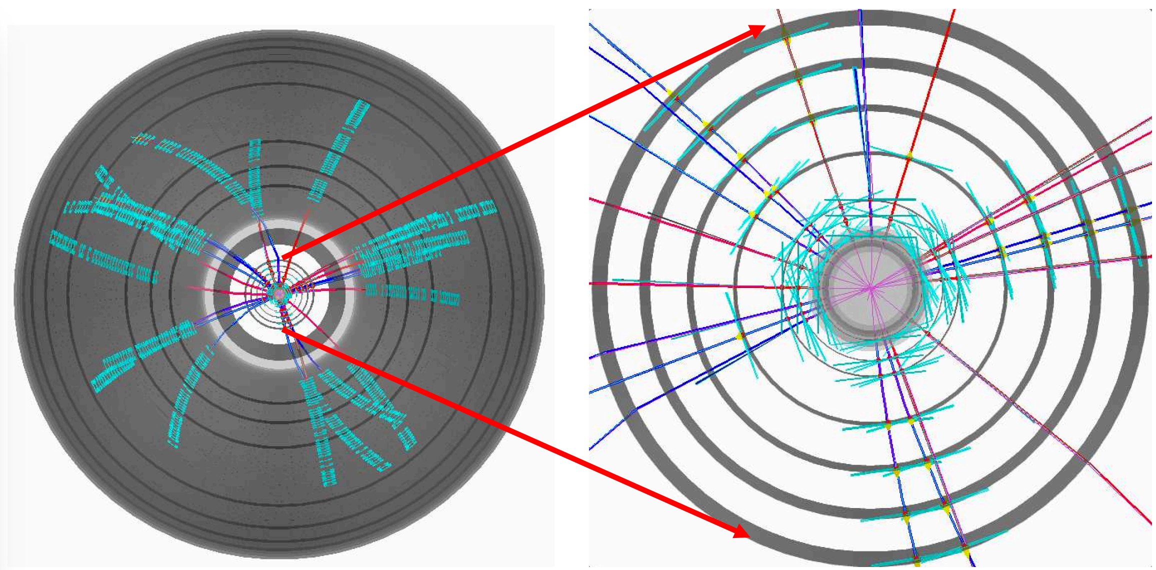
- p+p jetty event sample simulated in PYTHIA8 hard-QCD mode, jets with minimal pT of 20 GeV
- PYTHIA 8 20 GeV jets embedded into 0-4fm central HIJING events to study b-jet tagging in central Au+Au collisions
- Initial b-jet, l-jet cross-section from PYTHIA 8 simulation are with good consistency with previous PHENIX paper/FONLL calculation. This will be used to calculate the b-jet purity

Tracker: Geant4 used to simulate response of tracking detector

Reconstruction:

- Hough Transformation based pattern recognition
- GenFit2 based track fitting and DCA extrapolation.
- RAVE based vertexing





b-jet tagging: Impact Parameter Method

Reconstruction:

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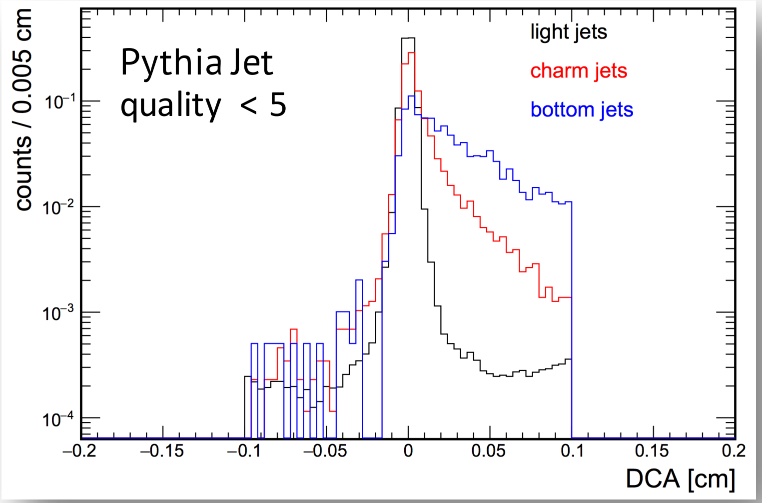
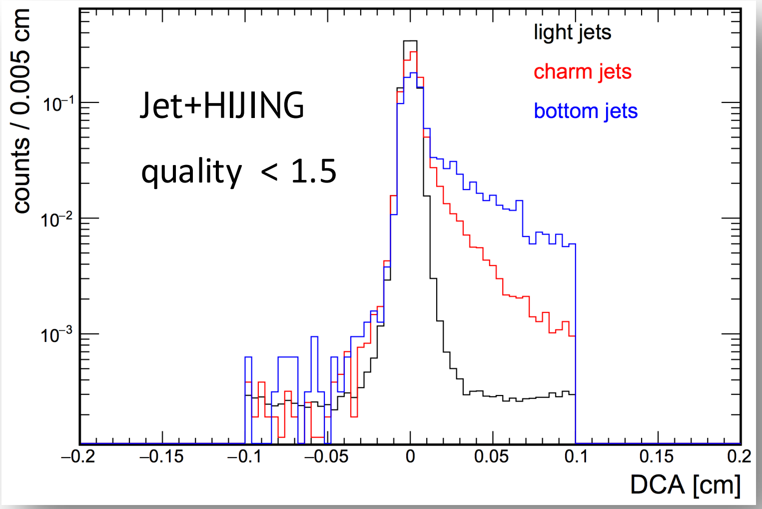
- Using RAVE in single vertexing mode for vertexing
- DCA_{xy} and DCA_z extrapolated with regarding to reconstructed vertex

b-jet tagging:

- Define $S_{DCA} = \sqrt{\left(\frac{DCA_{xy}}{\sigma_{DCA_{xy}}}\right)^2 + \left(\frac{DCA_z}{\sigma_{DCA_z}}\right)^2}$
- Sign of S_{DCA} defined as sign of $DCA\,Vector \cdot Jet\,Vector$
- Make different S_{DCA} cut for largest, second largest, third largest S_{DCA} track in a jet cone.
- From the efficiency vs. $S_{DCA,min}$ for l-jet, c-jet and b-jet, calculate l-jet/c-jet efficiency vs b-jet efficiency.
- Calculate b-jet purity vs. tagging efficiency based on initial ratio from Pythia.





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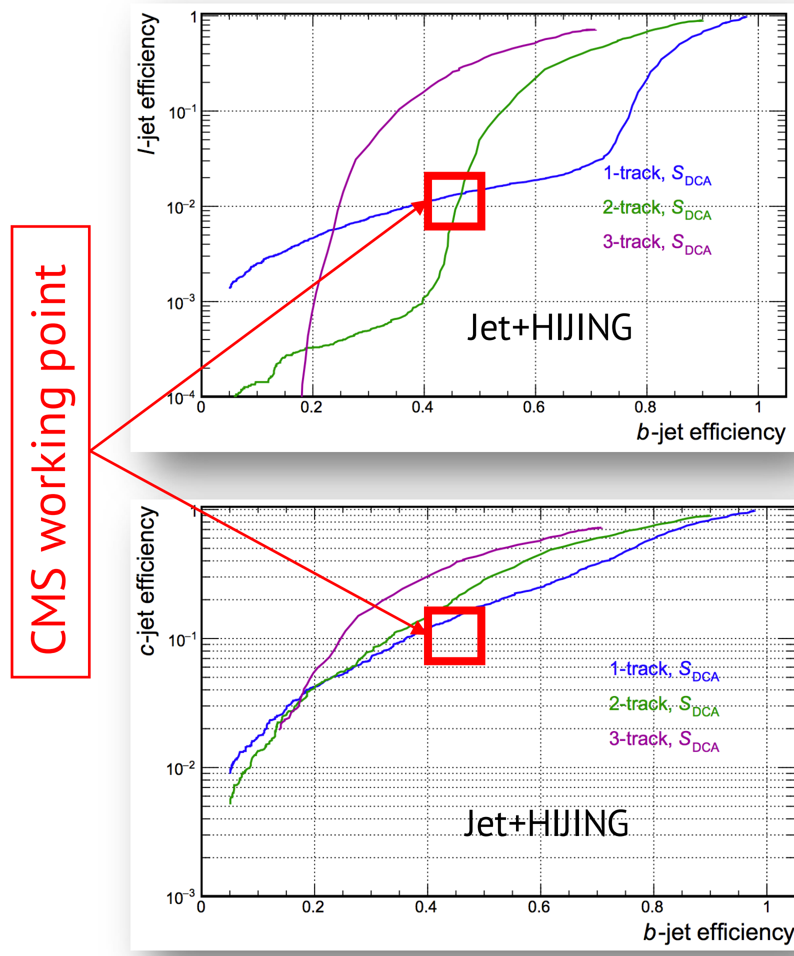

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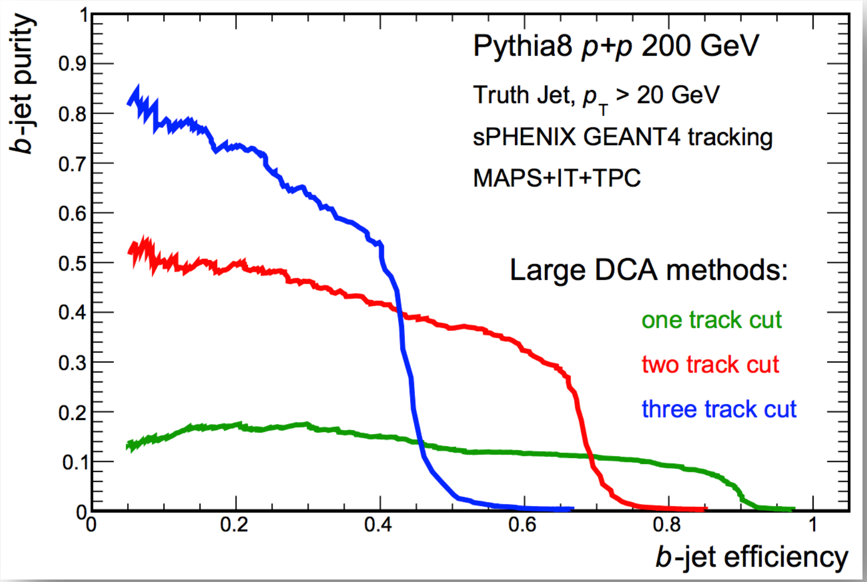
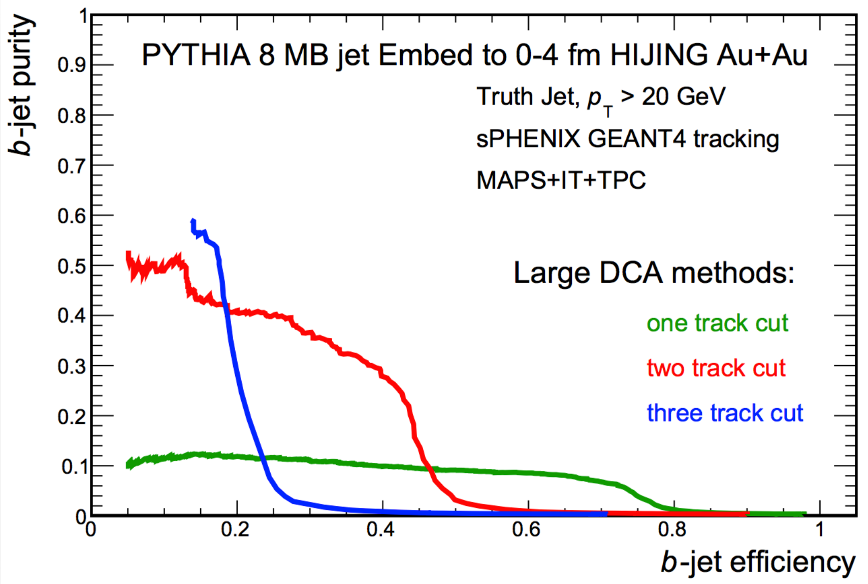
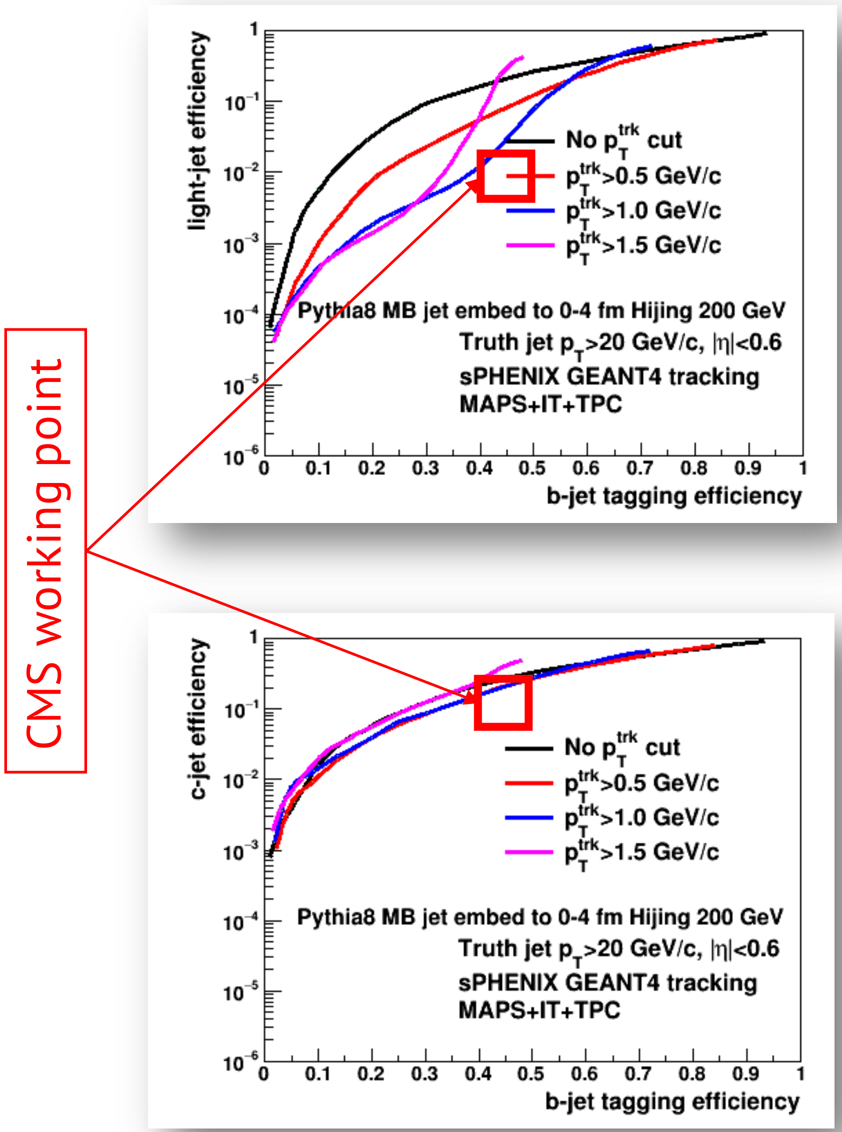




b-jet tagging: Secondary Vertex Method

b-jet tagging:

- Running RAVE first in single vertexing mode to reconstruct primary vertex (PV).
- Running RAVE with tracks in jet cones in multiple vertexing mode to reconstruct secondary vertices (SV).
- Make cut on sigmalized distance between PV and SV.
- Calculate b-jet purity vs. tagging efficiency as shown below



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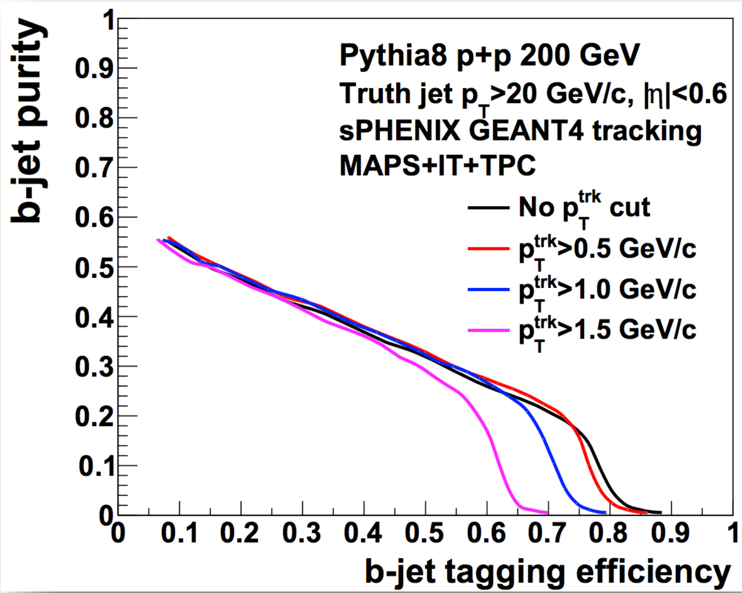
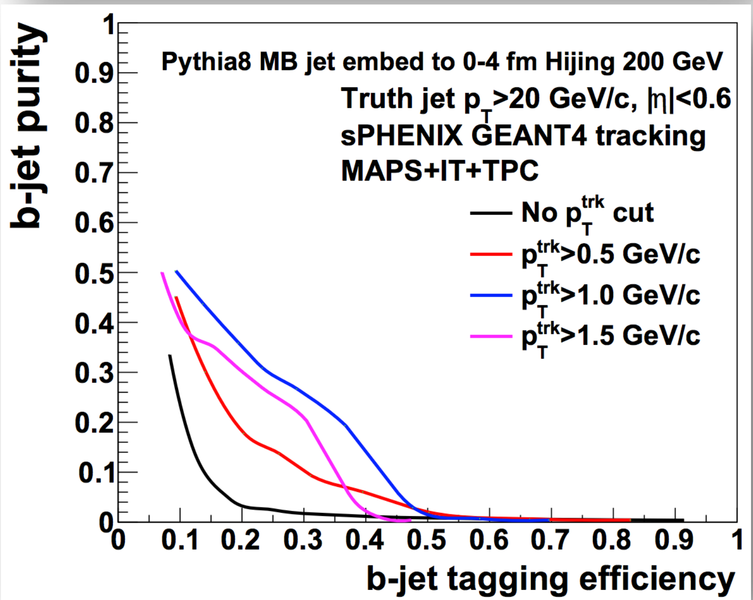




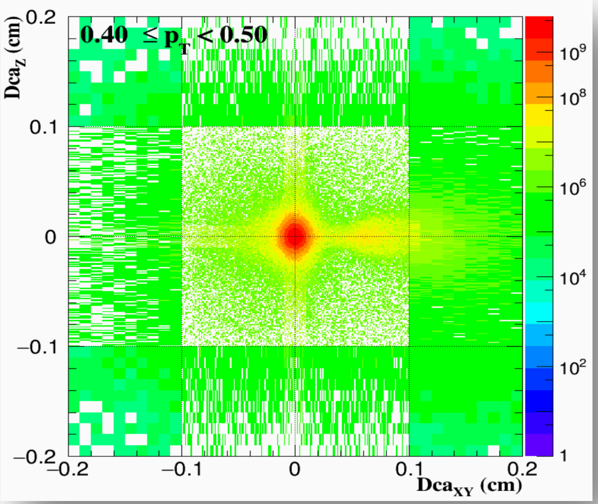
$B \longrightarrow D^0 \longrightarrow K\,\pi$

- $D^0 \longrightarrow K\,\pi$

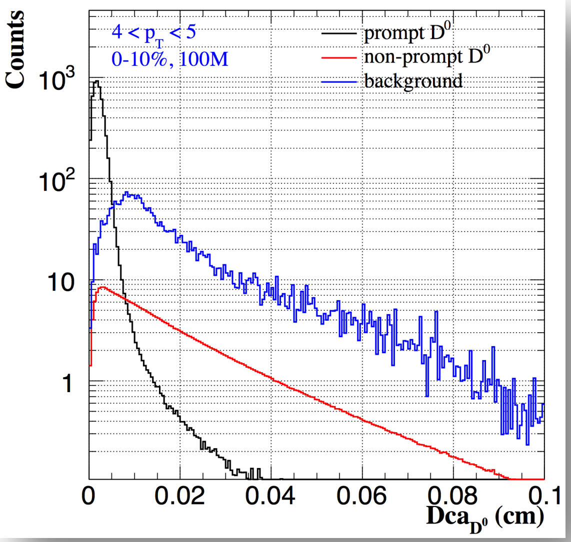
- Fast simulation package:

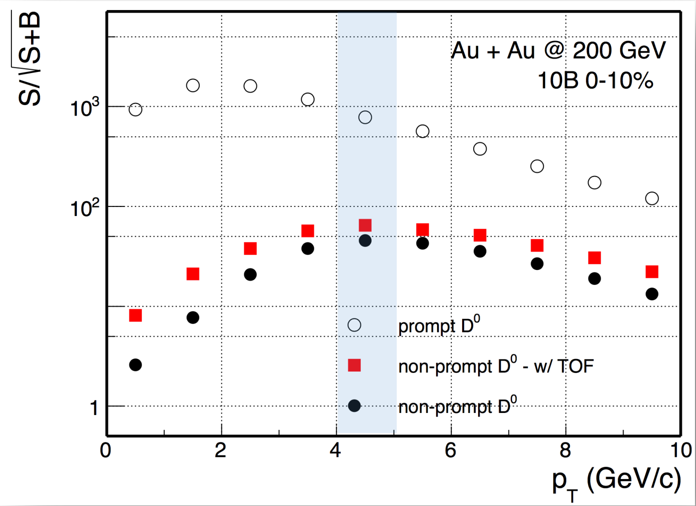
1) Sample event vtx distributions
2) Throw signal (D0, B) or background (pi,K,p from Hijing) tracks, decay if needed
3) Smear the track origin with (DCAxy, DCAz) 2D distributions
4) Smear the momentum according to the momentum resolution
5) Full reconstructed helices -> reconstruct secondary vertex
6) Calculate the signal efficiency or background accept-rate

- Analysis method similar as arXiv:1701.06060 (STAR)



FastSim





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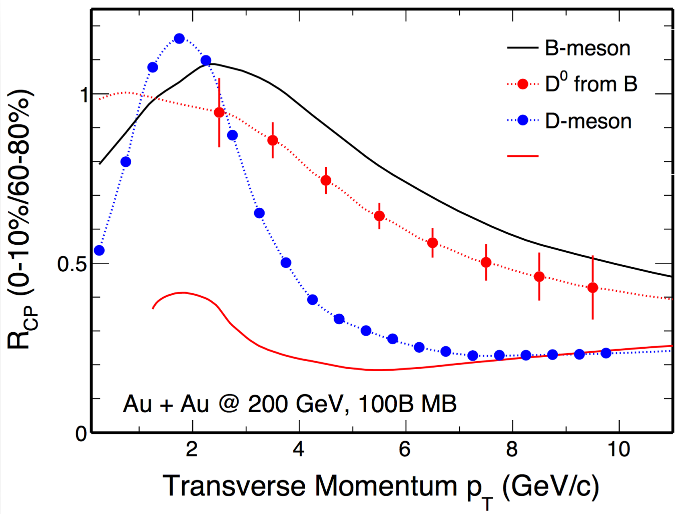
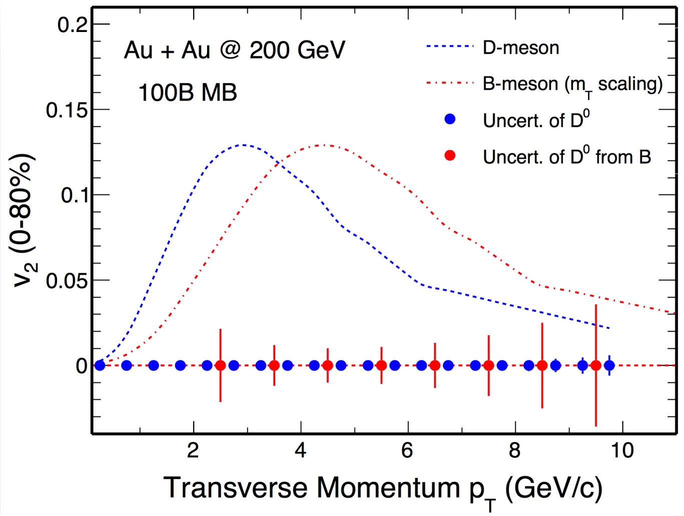
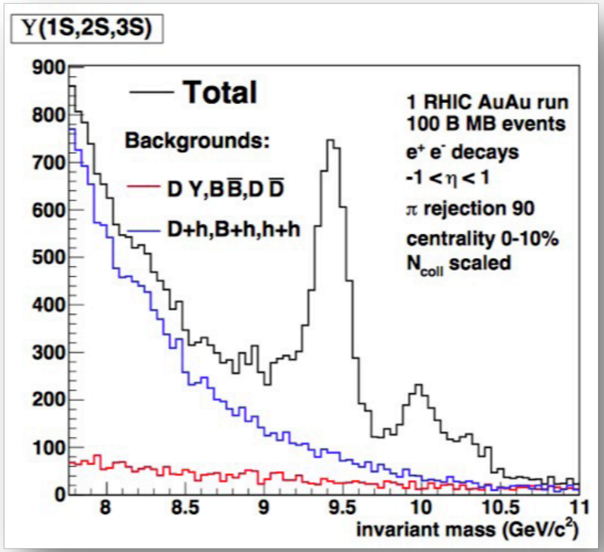
- Calculate expected statistical uncertainty of prompt/non-prompt D R_{CP} and V_2



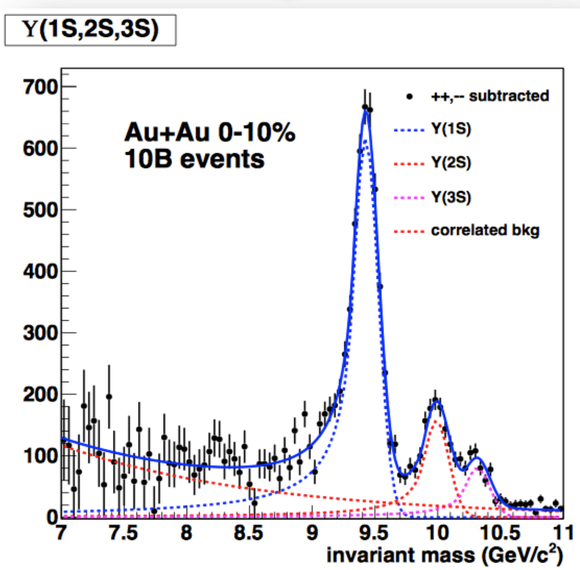


Upsilon ⟶ $e^+ + e^-$

- Upsilons provide an excellent probe for studying the screening length in the QGP
- eID: 100:1 pion rejection @ 90% electron eff. in Au+Au
  - Energy matching
  - Shower shape
- Tracking momentum resolution good enough to resolve three Υ states
- Combinatorial background shape taken from PHENIX π^0 spectra in Au+Au with eID rejection factor
  - Could be subtracted by mixing events
- Correlated background (bottom, charm semi-leptonic decays and DY) shape predicted by PYTHIA and scaled to PHENIX charm and bottom cross-section in Au+Au



Un-corr. Bg.
Subtraction



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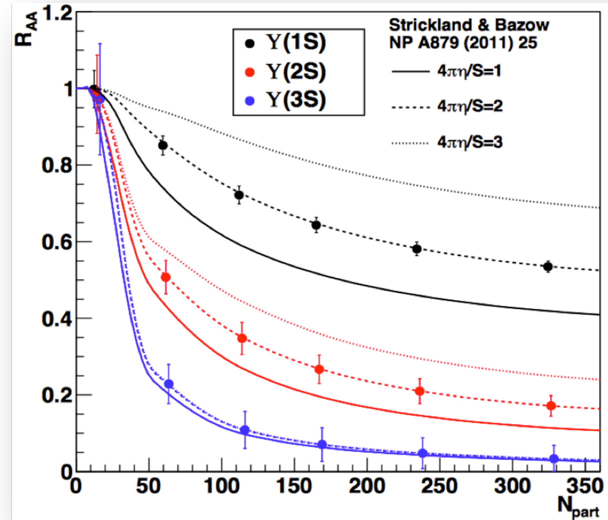
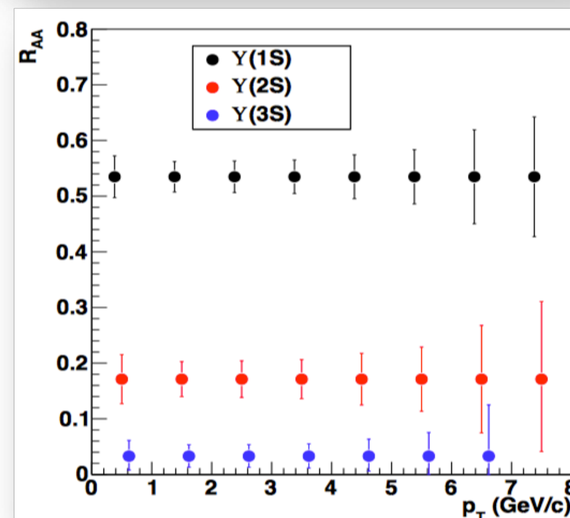
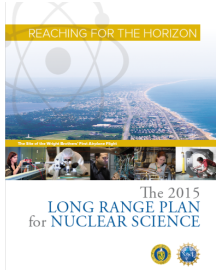
- Updated results with more detailed eID rejection and more sophisticated correlated background will be available soon.





2016 for sPHENIX

Oct 2015



Oct 2016

- ✓ Collaboration formed (Dec 2015)
- ✓ Successful magnet tests
- ✓ Successful Test Beam of calorimeter system
- ✓ Tracking system more defined: TPC + INTT + MAPS
- ✓ Improved simulations
- ✓ CD-0! Approve Mission Need
  - DOE project phase: **Initiation**

Summary and Outlook

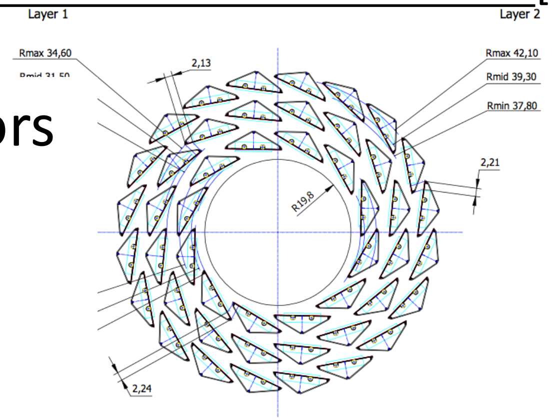
- sPHENIX Collaboration: 62 institutions, 235 collaborators & growing
- sPHENIX obtained CD-0 and working toward next stage
- Successful test beam in 2016 and new high eta test beam going on
- Tracking system more defined
  - MAPS, INTT, TPC
- Topical groups studying the physics goals with more sophisticated simulations
  - Jet Structure
  - Heavy Flavor Jet
  - Upsilon
  - Cold QCD

Backups

Tracking Subsystems

MAPS

R&D for the sPHENIX MAPS inner tracker [M. Liu]

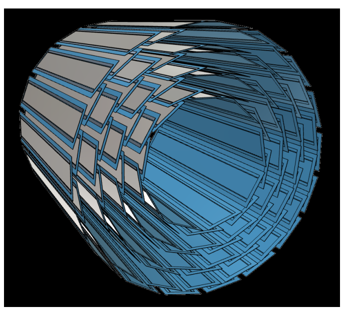


- 3 layers Si sensors
- Based on ALICE ITS upgrade
- $DCA_{xy} < 70$ µm
- $|z_{vtx}| < 10$ cm

sPHENIX TPC mechanical design K. Dehmelt

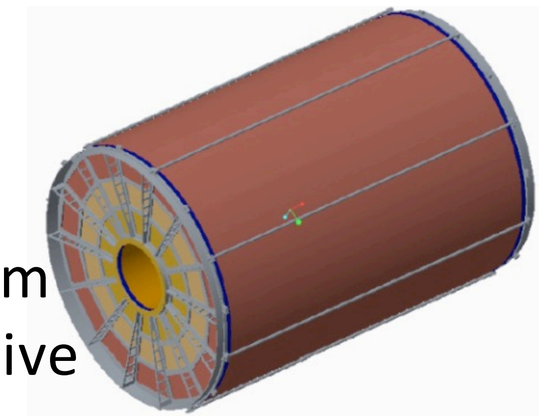
R&D Studies for the sPHENIX Time Projection Chamber P. Garg

INTT



- 4 layers Si strips
- Use PHENIX FVTX electronics
- Pattern recognition, DCA, connect tracking systems, reject pile-up

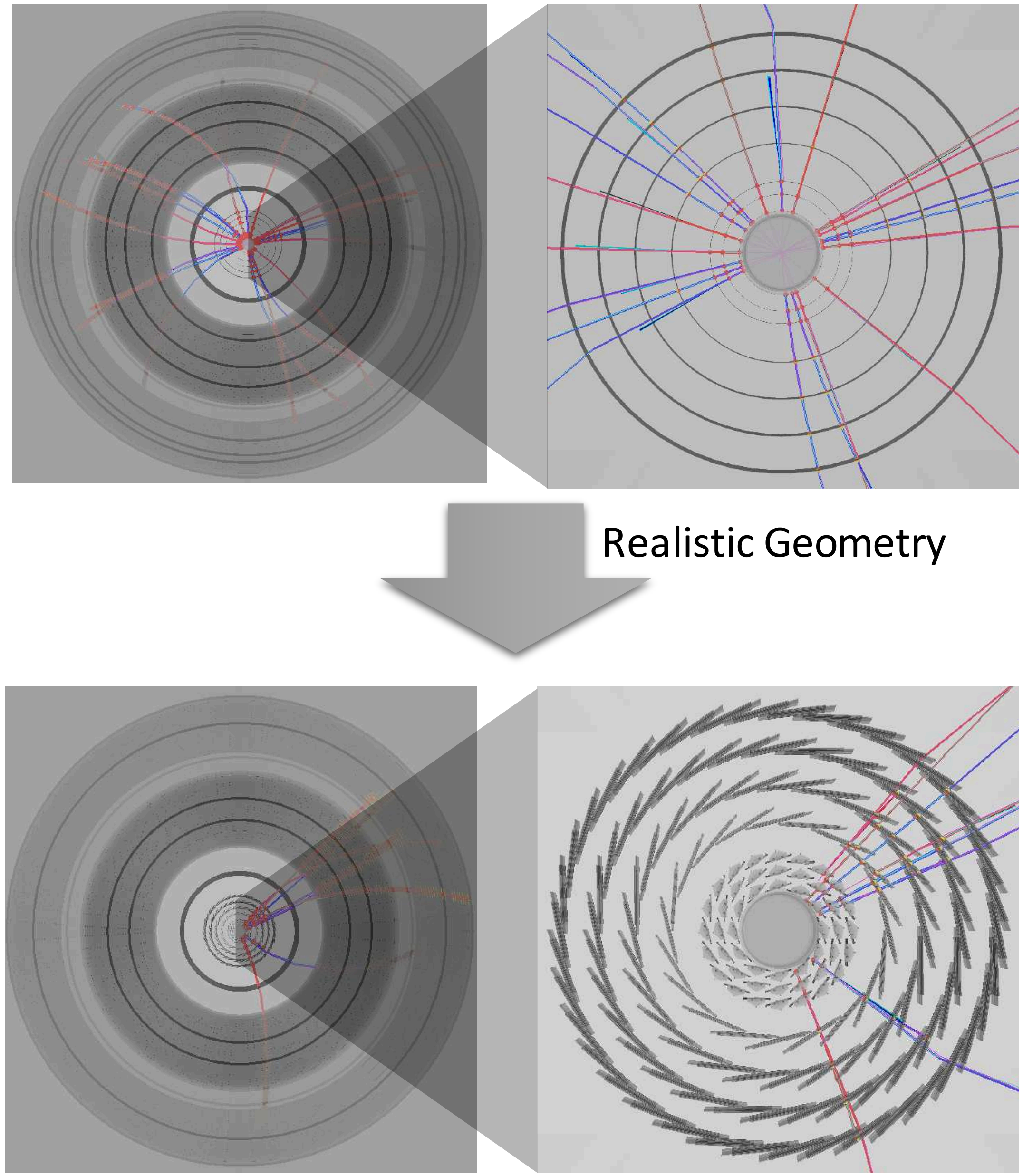
TPC



- Radius 20–78 cm
- ~250 µm effective hit resolution
- Continuous (non-gated) readout
- Pattern recognition, momentum resolution, p_T 0.2-40 GeV/c

The intermediate tracking system of the sPHENIX detector at RHIC G. Mitsuka

Realistic Geometry for Tracking Coming Soon



Photon clustering algorithm

- Algorithm A
  - Cluster = contiguous towers E > $E_{threshold}$
- Algorithm B
  - Noise reduction → E > $E_{threshold}$
    - Neighboring towers which satisfy noise threshold = "isolated cluster"
  - Find "local max tower" and "peak area" around it
  - E_{tower} with contribution from 2+ peak areas divided into peak areas
    - Parameterized shower shape function
  - Redefine "core cluster" within cluster area as towers E_{sum} > $E_{threshold}$ of peak area

Algorithm A **Algorithm B**